Supplying A Low-Voltage Continuous-Load From An Electrostatic Generator

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Abstract– **This paper mainly focuses on supplying low voltage continuous load from an electrostatic generator so that it can widely be used in the day to day domestic and industrial applications. Also, it will be discussing limitations and drawback of electrostatic generation and important consideration for dealing with this generation. It will be including a novel circuit which is very compatible in order to get the low reduced voltage and finally demonstrating the performance of proposed circuit using simulation model.**

Keywords: **continuous load, Electrostatic generator, PI controller**

I. INTRODUCTION

An electrostatic generator or electrostatic machine is a mechanical device that produces static electricity or electricity at high voltage, however, at low power levels. The knowledge of static electricity was discussed in mid sixteenth century but merely as an interesting and mystifying phenomenon and often confused with magnetism. By the end of 17th century, researchers had developed practical means of generating electricity by friction , but the development of electrostatic machine didn't begin in earnest until the 18th century, when they became fundamental instrument in the studies about the new science of electricity.

II. MODELLING OF AN ELECTROSTATIC GENERATOR

The electrostatic generator can be modelled as high voltage source and a switch in series with it. The duty cycle of this switch shall actually determine the rate at which charge is collected at its electrodes. This means if electrostatic generator is having higher capacity it shall have higher voltage and high duty cycle may be used.

From Fig. 1 we can easily observe that the high voltage VH can be divided among two capacitances. We shall keep the value of resistance R to be very small to have very small time constant. This will ensure the rapid charging of capacitors and the voltage across capacitor C2 can be determined as follows.

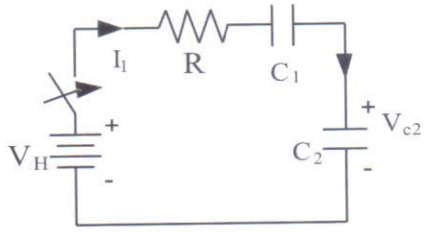

Fig.1 The model showing electrostatic generator voltage division across two capacitors.

The value of current i_1 in the circuit is

$$i_1(t)=I_0 e^{-t/(R.C_{eq})} \quad (1)$$

where $I_0 = V_H/R$. &

$$C_{eq}=(1/C_1+1/C_2)^{-1} \quad (2)$$

Also, $I_1(s) = V_H/\{s(R+1/sC_{eq})\}$

The value of Capacitor voltage C_2 will be

$$V_{C2}(s) = I_1(s)/(sC_2) \quad (3)$$

$$V_{C2}(s) = V_H/\{s(R+1/sC_{eq})\} \;.\; 1/(sC_2)$$

$$V_{C2}(s) = V_H/C_2/\{s^2.(R+1/sC_{eq})\}$$

$$= V_H.C_{eq}/C_2 \;.\; 1/\{s(s+1/RC_{eq})\}$$

$$v_{C2}(t) = V_H.C_{eq}/C_2.[1-e^{-t/(R.C_{eq})}] \quad (4)$$

If value of $t << RC_{eq}$: $v_{C2}(t) \approx 0$

If value of $t >> RC_{eq}$: $v_{C2}(t) \approx V_H.C_{eq}/C_2$

The variation of voltage across capacitor C_2 is shown in the Fig 2 for the values used for model. From this plot it is seen that the low voltage (500 V from 10^5 V source) can be obtained by selecting the suitable values of C_1 and C_2 and keeping the time constant of the series combination to be small. However the final voltage across the load shall also depend on the rate at which the charge is removed from the capacitor C_2 at which low voltage is obtained.

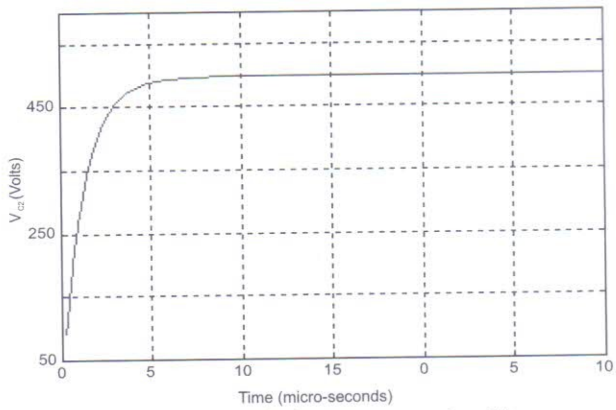

Fig.2 Variation of voltage across capacitor C2

III. PROBLEM FORMULATION

The aim of this paper is to build a novel circuit for converting the high voltage to low voltage of an electrostatic generator so it can be used as day to day purpose.

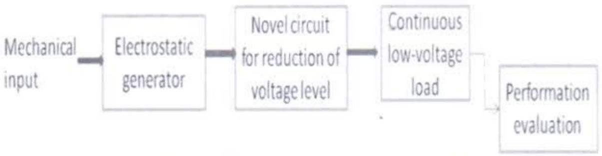

Fig (a): Block diagram representation supplying LVCL from electrostatic generator.

A. Proposed Circuit

The modification of this basic circuit just described has been carried out to achieve quick charging of capacitor C_2 and its controlled discharging to obtain desired constant power. This circuit is given in Fig.3(a).

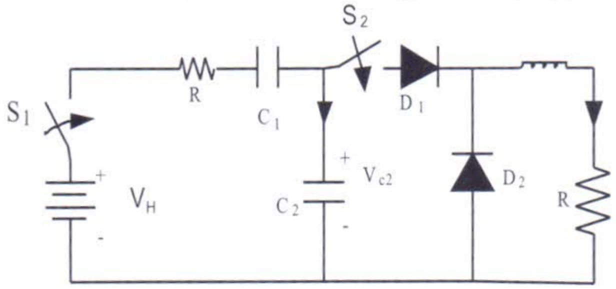

Fig.3(a) The proposed circuit to supply low-voltage load at constant current.

The method of fast charging of capacitor C_2 and its controlled discharging to obtain desired constant power is achieved by controlling the switch S_1 and S_2. The operation of switch S_1 and S_2 is kept 180° out of phase. For the first part of cycle, charge is transferred from electrostatic generator V_H to capacitor C2. During second part of the cycle, charge from C_2 is transferred to the load. An inductor is put in series with load resistance to have constant current. The diode D_1 shall prevent flow of load current in reverse direction while diode D_2 is a free-wheeling diode. When S2 is open, D_2 provides an alternative path for load-current to discharge the stored energy in inductor.

B. Control Strategy

A current controller is designed to obtain the value of desired current I_{ref}. The actual load current I_{Load} shall be measured and shall be fed back to the current controller for comparison and generation of command signal pulse. The control strategy is shown in Fig. 3(b)

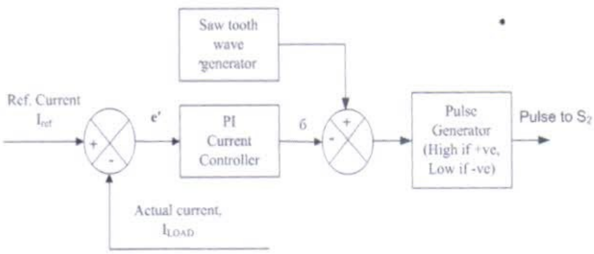

Fig. 3(b) Pulse generation for controlling duty cycle of S2.

C. Modelling of PI Controller

In PI controller the actual current $I_{act[n]}$ is compared with the reference current $I_{ref}{}^*{}_{[n]}$ and the resulting error in the current, $e'_{[n]}$ is calculated at nth sampling instant as :

$$e'_{[n]} = I_{ref}{}^*{}_{[n]} - I_{act[n]} \tag{5}$$

The magnitude of sign may be positive or negative depending upon the actual current and its reference value. The output of the PI controller at the nth sampling instant is:

$$T_{[n]} = T_{[n-1]} + K_p \cdot (e'_{[n]} - e'_{[n-1]}) + K_i \cdot e'_{[n]} \tag{6}$$

Where K_p and K_i are the proportional and integral gains of the speed controller respectively. The output of speed controller must be saturated based on the rating of system as follows:

$T_{[n]} = T_{max}$ if $T_{[n]} > T_{max}$

$T_{[n]} = -T_{max}$ if $T_{[n]} < -T_{max}$

$\partial^* = T_{[n]}/K_t$

Where, $T_{[n]}$ is the reference duty cycle for nth instant

$T_{[n-1]}$ is the reference duty cycle for previous instant

K_p is proportional gain

K_i is integral gain

e'[n] is current error at this instant

e'[n-1]is current error of previous instant

K_t is saturation constant of system

∂^* is the reference duty cycle

D. Modeling of Pulse generator

In duty cycle obtained from PI controller is compared with a saw-tooth carrier waveform in such a way that the modulation index is always less than or equal to 1.

The modeling of saw-tooth carrier is an important aspect for Pulse generator. The magnitude, "mag" of triangular carrier is found at an instant "t" as follows:

mag = amp_tri * K

where, amp_tri is the amplitude of triangular carrier wave,

K= modulus(t, T)/ T for t between 0 & T

Where, T is time-period of triangular carrier wave

The switching function is generated from the duty cycle ∂ and saw-tooth carrier magnitude at any instant as follows:

If (∂<=mag_tri) SF=0

If (∂>mag_tri) SF=1

I. Simulation of Circuit

A simulation model has been developed using MATLAB software employing its SIMULINK/ SimPowerSystem Toolboxes. This model is shown in Fig.4. The analysis has been carried out using ODE23tb continuous solver. The details of controller model can be seen in Fig.5

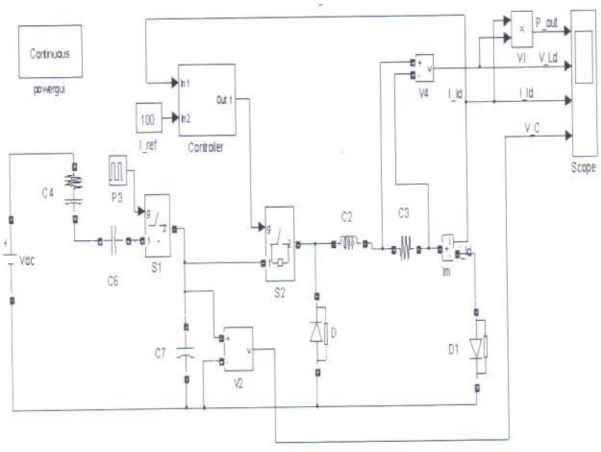

Fig. 4. MATLAB model for simulation of developed configuration for getting continuous output power at reduced voltage.

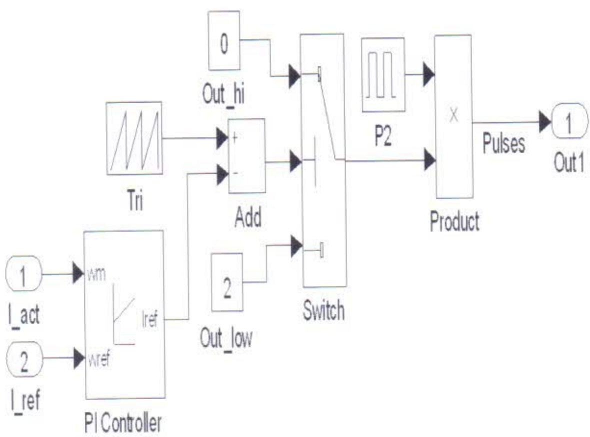

Fig. 5 The controller Model employing MATLAB.

V. RESULTS AND DISCUSSION

Fig.6 shows the simulation results obtained from developed model. The variation in output power obtained with time according to command signals along with the voltage waveform across the resistive load, variation in load current as per command and variation in voltage across output capacitor can be seen. It can be seen that the variations in waveforms are according to the command signal.

Initially the load current is 50 A which changes to 100A at 0.4ms and at 1ms it settles to 20 A, as per the desired command signal. Also, the power is 5kW, 17kW and 2kW at those instants. Moreover, it is observed that the voltage across load and capacitor C_2 remains less than 600V at all instants. This has established the validity of proposed model and control strategy.

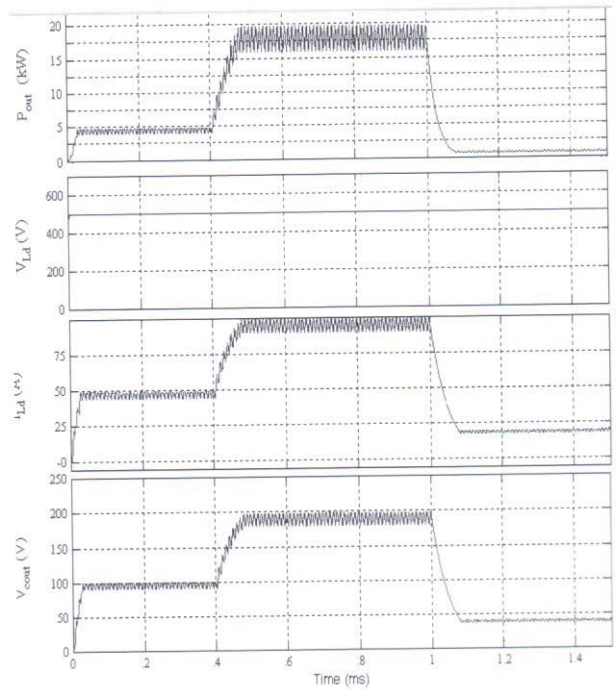

Fig.6. Figure showing simulation results –(a) variation in output power obtained with time according to command signals (b) Voltage waveform across the resistive load (c)Variation in load current as per command (d) Variation in voltage across output capacitor.

VI. CONCLUSIONS

It has been observed that the proposed system is capable of converting high voltage into low voltage and it supplies continuous constant current to load. Such a system is very suitable for controlled heating applications supplied from electrostatic generator.

We must ensure following conditions in the system:

(a) The time constant for charging the capacitor C_2 should be very small. This shall require capacitors which have very low resistance of their own and its leads.

(b) The mechanism for generating charge at very high rates (of the order of few micro-seconds) will depend on electrostatic generator design, which may actually be complex and bulky.

(c) The large value voltage will be acting across capacitor C_1, therefore, more number of larger capacitance capacitors are to be placed in series. Moreover, the high level of insulation requirement will be there in this part.

(d) To have high frequency switching MOSFETs must be employed. Protection of MOSFET for S_1 will be crucial.

It is concluded that by meeting the above stated constraints an electrostatic generator can be successfully employed for low-voltage, continuous loads.

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